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PATENT SPECIFICATION

DRAWINGS ATTACHED

889,583

Date of Application and filing Complete Specification: April 22, 1960. *No. 14279/60.*

Application made in United States of America on April 27, 1959.

Complete Specification Published: Feb. 21, 1962.

Index at Acceptance:—Class 82(1), Y1, Y2(A1 ; A2 ; K : M : Q : R : S : T : V : Y : Z3 : Z4 ; Z5 : Z12); Y3.

International Classification:—B23n.

COMPLETE SPECIFICATION

Improvements in or relating to the Manufacture of Fibre Metal Compacts

We, ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY, a Corporation of the State of Illinois, United States of America, of 10 West 35th Street, Chicago 16, Illinois, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement;—

The present invention relates to fibre metal compacts, and more specifically relates to a process whereby fibre metal compacts possessed of varying controlled degrees of porosity and strength are rapidly and conveniently formed and to the compacts produced by such process.

In the art of fibre metallurgy use is made of metallic constituents whose physical properties intermediately range between metal powders on the one hand and metal filaments as used in the metal wool arts on the other, and as is discussed in considerable detail below, by the utilization of such constituents as herein taught there results bodies or compacts thereof which markedly differ in many respects from powder metal or metal wool bodies. Even more particularly, by the practice of our invention metal compacts having desirable physical properties are produced from such raw materials consisting mainly or entirely of metal fibres. The compacts resulting from the use of the present process are characterized by a unique combination of porosity and mechanical strength to make them particularly useful as filtering media, boundary layer control devices, transpiration cooling elements, heat exchange materials, bearings, electrical brushes, magnetic circuit elements, and in numerous other areas where their desirable characteristics enable them to be beneficially employed.

In view of the foregoing considerations, a primary object of our invention is to provide a novel method of forming fibre metal compacts.

Another object of our invention is to provide a method of making fibre metal compacts or bodies by the process which includes the step of air-felting metal fibres.

According to the present invention, a process for making a fibre metal compact comprises releasing separate fibres in a gaseous medium so that the fibres are randomly oriented by the gaseous medium and collect into a randomly oriented mass of fibres, and bonding the fibres in the mass to each other at their points of contact, each fibre having a length of from 0·005 to 1·0", and a mean cross-section of from 0·0005 to 0·1" and not greater than one tenth of the length of such fibre.

Likewise a fibre metal compact according to the present invention is formed by releasing separate fibres in a gaseous medium so that the fibres are randomly oriented by the gaseous medium and collect into a randomly oriented mass of fibres, and bonding the fibres in the mass to each other at their points of contact, each fibre having a length of from 0·005 to 1·0 inches and a mean cross-section of from 0·0005 to 0·1" and not greater than one tenth of the length of such fibre. The invention will be more readily understood by those skilled in this particular art from the following detailed disclosure of the embodiments thereof, particularly when considered in conjunction with the accompanying drawings in which:

Figure 1 illustrates one convenient procedure for carrying out the air or gas-felting step of our invention wherein the constituent metal fibers are passed through a vibrating screen through air or other gases into a mould of the desired end product shape;

Figure 2 represents a somewhat more elaborate continuous method of practicing the air-felting step of the present invention whereby lengthy, continuous sheets of fiber metal materials are rapidly formed;

Figure 3 illustrates an autogenously bonded fiber metal body produced in accord herewith; and

Figure 4 illustrates a highly magnified view of a sinter bonded metal compact resulting from our process.

To best understand our invention and the benefits and advantages thereof at the onset should be considered exactly what is encompassed within and meant by the term "metal fiber" as used in the present specification and claims. Such term represents a class of materials distinct from the long length filaments utilized in the metal wool industry, and as a critical distinction such filaments are not permissible raw materials in the practice of our invention and from which to fabricate the desirable products resulting from our process. On the other hand, as indicated above, the term "metal fiber" represents a distinct entity from the raw materials used in the powder metallurgical arts. For purposes of nomenclature we have borrowed from the fabric industry the term "staple" to denote a short length fiber as being most closely comparable to the metal fibers used herein and, as is discussed below in somewhat more critical terms, it is to the fabrication of compacts from such staple length fibers that the present invention is directed. In distinction to the filaments comprising steel wool or metallic wools generally it is essential to the success of our invention that short length fibers be used to ensure that a random fiber distribution be obtained and further that such randomness provide a uniformly porous fiber metal body. Such uniformity is unobtainable with compacts of steel wool since the long length fibers are not formable into a randomly oriented mass. On the other hand, bodies formed of metal powders do not illustrate any particular degree of strength unless they are extremely dense—because of the powder structure considerable compaction is required to achieve thorough bonding of the powder particles.

At first glance the art seemingly most closely related to the present invention is the manufacture of steel wool pads. In such art comparatively long length filaments or ribbons, i.e., from several inches up to several feet in length, are shaved from a metal body base, such base usually being in the form of a rod which is drawn across an appropriate cutting tool. A multitude of such resultant filaments are gathered together, primarily in the shape of parallel lines and are then cut or compressed to the selected mass form for the desired end usage. When utilizing such steel wool articles it is evident that they possess considerable strength in the direction of the long axis of the individual fibers, but it is also apparent that such bodies may be readily dissected or separated even after bonding of the filaments by forces imposed at a direction at an angle to the major or long fiber axis. This is to say that such steel wool pads illustrate the strength of their metallic components in a direction along their major axis, but it is further apparent to any user of such articles that the filaments may be easily separated and in fact with even slight care rather long filaments may be extracted without rupture from the steel wool mass. In comparison to the steel wool compacts such dissectability and lack of strength along the axis not parallel with the major axis of the filaments are not found in articles produced in accordance with the process of the present invention; in fact with our invention one cannot speak of a major fiber axis because of the random distribution and lack of orientation of the metal fibers comprising the present compacts.

In another somewhat related art, namely, powder metallurgy, spheres or semi-spheres of various selected metals are compressed and bonded to form various articles of manufacture. In distinction to both metal wool and fiber metallurgical articles, the products resulting from powder metallurgy techniques are, if they are to exhibit any strength property, usually exceptionally dense and lack practically any degree of porosity because of the fact that in order to bond the metal powders exceptionally close contact and compaction are required. As a practical matter the results of powder metallurgy are in many aspects almost indistinct from the well-known solid pyrometallurgical products.

In our process of forming fiber metal compacts comparatively short length fibers, i.e., from 0·005 to 1·0 inch are randomly formed into sheets, shapes and articles of manufacture. Such products do not suffer the ease of dissection or non-parallel lack of strength of the steel wools or metal wools generally yet can be formed into porous masses having a density of from 5% to above 95% in distinction to the articles formed of powder metals.

Since the length of the fibers is so important to the successful use of our process and the characteristics of the end product resulting therefrom such "short length" limitation should be even more critically considered. That these are staple length fibers and not powders, flakes, chips or long length filaments, all of which are inoperative for the purposes of the present invention has already been mentioned. As employed in the instant specification and claims in addition to the foregoing specific numerical limitation by the term "metal fiber" is meant an elongated metallic body having a long dimension substantially greater than its mean dimension in cross-section, and as a general rule the fiber should have a length of at least ten times such mean dimension. By the term "mean dimension in cross-section" is meant the diameter of the cross-section in the case of a circular sectioned fiber or in the case of a rectangular or rectangular-like sectioned fiber such term denotes one-half the sum of the short side and the long side of such rectangle. The absolute length of the fibers must be such that by the hereindescribed process a random array of fibers is constantly achieved by air-felting or a like dry-felting procedure. In addition to the specific length

limitations aforementioned (i.e., 0·005 to 1·0 inch) the average mean dimension in cross-section of such fibers may vary from 0·1 down to 0·0005 inches. Fibers substantially longer than the upper limitations hereinmentioned fall within the category of filaments and are inoperative for the purposes of the present invention.

A further apparent critical limitation upon fiber lengths are the dimensions of the fiber metal compact itself. In the usual three-dimensional product, as for example, a sheet or blanket of such materials, we have found that the fiber length should be substantially less than the two major dimensions of such body and even more particularly in practical operation that such fibers should never exceed one-third the length of either such major dimension.

The restrictions in fiber length are necessary in order to prevent what is termed "bridging" in the fabrication of articles from such fibers. If the average fiber length is too great, as various irregular cavities are initially produced during the air-felting procedure the subsequent deposition of fibers results in such fibers bridging across the walls of the voids and thus prevents the filling of such voids from the matted array. In our procedure, on the other hand, such evacuated spaces are eliminated almost immediately upon their formation since the fibers are of such selected lengths that as the voids are temporarily created other subsequently entering fibers drop into and adequately fill such spaces. This provision for the elimination of voids is extremely important to maintain the integrity, strength, uniformity and porosity of the articles made by our process and we think it evident to those skilled in this particular art that this feature is not available with the use of either the long length filaments of the steel wool industry or the powder metals.

While our process is primarily for use with either uncoated metal or alloy fibers it may also be employed with fibers that have a thin, metallic brazing compound or the like deposited thereon.

More specifically, starting with the aforesaid metal fibers which may be produced by cutting wires to the desired length or other equivalent procedures, such procedures not being a feature of the present invention, in the preferred embodiment our process involves the vibrational screening of such fibers either into a molding form or onto a continuously moving belt or web, such fibers being deposited with a random orientation for strength and porosity purposes. Following their formation into a three-dimensional matted mass, for most purposes, the fibers are sinter bonded or brazed to increase the strength of the finished article. Furthermore, in order to provide the greatest degree of "green", i.e., unsintered, strength and to improve the possible isotropic properties of the sintered compact we have found that it is desirable that the fibers be kinked prior to their deposition in accord with our process and it should be clearly understood that in the preferred usage hereof the fibers are so kinked. While the term "kinked" is well-known, to preclude any misunderstanding by such term is meant that the direction of the major fiber axis is changed two or three times along the length of the fiber. In some instance, such kinking may be 90° or more but such angle will depend upon the procedure used and the equipment most readily available to the operator utilizing the instant process. We have found that by kinking the fibers followed by random array deposition that there results a marked increase in the coherency of the fibers prior to their bonding. Another factor to consider at this point is that in some instances by the use of the hereindescribed vibrational technique prior to air-felting the present fibers may be kinked and thus a separate kinking step may be unnecessary.

REFERRING NOW TO THE DRAWINGS:

In Figure 1 kinked metal fibers 11 are illustrated dropping through air into the mold, 12, after their passage through the vibratory screen 13. Such fibers form the compact 14 within the confines of the mold and readily assume the shape thereof. In this particular apparatus the screen 13 may most simply be vibrated manually and to this end handles 15 are peripherally attached thereto. If the operator wishes, other means of vibration may be used, as for example such as are provided by electromagnetic forces.

It should be understood that the mold 12 may be of substantially any desired shape or dimension, and further, that the fibers may be of practically any metal or combination of metals which meet the particular property requirements of the user hereof.

Figure 2 discloses a somewhat more complex method of forming a continuous sheet of fiber metals. In such process the short length, kinked metal fibers 11 are continuously fed from the belt 16 onto a vibratory screen 17 through which they drop onto a second moving belt 18, and in dropping, are formed into the randomly oriented sheet 19, and are felted therein.

After the formation of the compact or sheet by the foregoing air-felting procedure, in the next step in the preferred embodiments hereof the fibers are bonded together at their points of contact. How this is accomplished will depend upon the density required of the finished article, and, in some instances, the metal of which it is formed. We have found that by air-felting or dry-felting alone it is possible to form a fiber metal body having a density of from 5% to 20% of a solid metal article of equivalent size and composition. For some uses this density is permissible in which case it is merely necessary for example, to heat the compact to its sintering temperature to achieve bonding. Such is most readily

accomplished by placing the compact or sheet in a heating chamber and holding it at the required temperature for the necessary time, such matters depending on the particular metal being used. On the other hand, it is possible to produce fiber metal bodies of up to 95% of theoretical density, in which instance a compaction technique is required. This may be accomplished in a multitude of ways at the discretion of the operator, but in general either the material is compressed and sintered simultaneously—"hot pressing", or is compressed and then sintered in two separate operations. More specifically, the sheet resulting from the apparatus of Figure 2 may be passed directly through one or more pairs of hot rolls for compression and/or sintering whereas the compact 14 (Fig. 1) is most conveniently positioned in a die and compressed cold or hot pressed. It should also be understood that the temperature required for sinter bonding not only will vary with the metal or alloy which forms the fiber metal mass, but further, that such composition will determine the special atmosphere, if any, required for the sintering procedure.

Figure 3 illustrates a three-dimensional compact formed by our process. As is evident from the drawing, such compact is composed of a multitude of randomly oriented, short-length fibers 11, bonded inter se.

In Figure 4 is disclosed a magnified view of a small portion of the compact of Figure 3 to illustrate the sinter bonding of the fibers 11. The autogenously bonded mass is important in providing the strength values of the present compacts. In fact, due to such bonding, upon the application of extreme stress to the mass, rupture occurs not at such autogenous bonds, but across an individual fiber. This is not only to say that upon the formation of an autogenous bond that the tensile strength thereof is greater than that of a fiber, but also, in view of the large number of bond formations encountered by each fiber, there results porous compacts of great tensile strength. Such is particularly true since the number of bonds (i.e., bonding points) along the length of a fiber may range from two to fifty or more.

In order to successfully employ our process in the fabrication of uniform bodies, it is necessary during felting through air that the weight of the fibers per unit area of the mat or compact being deposited be substantially uniform. More specifically, for example, if 10 grams of fibers fall in one minute such weight should be substantially equally distributed over the entire face of the compact. This is particularly true if the fibers are falling into a static mold. In the case of deposition onto a moving belt, this requirement should also be met—drop weight per unit area should remain as constant as possible to assure the formation of a fiber metal blank of uniform physical properties.

The second requirement of our process follows from the necessity of forming the present compact with random fiber orientation. To fulfill this it is necessary that the fibers fall in a random manner—i.e., lacking any regular alignment in direction.

In practice the foregoing requirements of uniform fiber weight and random distribution are controlled by suitably selecting the frequency and amplitude of vibration of the fiber screen or feed hopper, the screen size and the drop height of the fibers. All of such variables should be adjusted for a particular mass, length, diameter and degree of kinking for a particular fiber type. Our work with such process has indicated that the following are useful ranges for such variables although broader ranges could possibly be used:

(a) The amplitude of the screen may be selected from an estimated 0·001 inch to 6 inches.

(b) The frequency of vibration may range from 3 cycles per second to over 1000 cps. We prefer to use 60 cps.

(c) The screen openings may vary from 0·01 to 1·0 inches and the drop height may range from 0·5 to 84 inches.

It will be understood that within the range of the hereinabove disclosed parameters the present process can be used successfully in the manufacture of metal fibre articles. It will, of course, be recognized by those skilled in this art that in accord with the teachings of our invention fibre metal articles of almost unlimited cross-sectional area may be produced. Furthermore, the rate of production of such articles may be extremely high and further that articles of unlimited size as well as cross-section may be produced with the suitable design of a forming mold, or technique.

In order that our invention may be more fully understood the following examples illustrating the making of a series of fibre metal compositions are presented:

EXAMPLE 1

Fibres made from steel containing a maximum of 0·12% carbon, a maximum of 1·0% manganese, a maximum of about 1·0% silicon, a maximum of about 0·040% phosphorous, a maximum of about 0·030% sulphur and about 14% to 18% chromium and approximately 0·005 inch diameter and ½ inch long were vibrated through a screen in air into a suitable mold from the screen having openings of approx. 0·033 inches. The drop height was 8 inches, vibrations were at approximately 3 cycles per second and the amplitude of vibration was approximately 4 inches. Following its formation the mat was sinter bonded at 2400°F. in a dry hydrogen atmosphere.

The following table illustrates additional examples of the formation of fiber metal compacts. In all such cases the drop height was 8 inches, vibration was at approximately 3 cycles per second and the amplitude of vibration was approximately 4 inches.

TABLE 1

Fiber Material	Fiber Size	Sintering Temperature, °F	
Mild Steel (SAE 1010)	¼" x 0·005"	2100	(1)
Molybdenum	0·1 x 0·001	3200–3600	(1)
Silver	¼ x 0·005	1650	(2)
Brass (60% Cu, 40% Zn)	¼ x 0·005	1475	(3)
Bronze (90% Cu, 10% Sn)	¼ x 0·005	1300–1400	(3)
Aluminum	⅛ x 0·005	700–1060	(4)
Nickel	¼ x 0·005	1100–2200	(1)
Tungsten	¼ x 0·005	3600–4000	(1)
Platinum	¼ x 0·005	2750	(5)
Nickel Plated Molybdenum (plating 0·001–0·001" thick)	¼ x 0·005	2300–2800	(1)
SAE 1010 mild steel plated with chromium (0·00001–0·001" thick)	¼ x 0·005	2100–2450	(1)
Nickel and Molybdenum (cofelted)	¼ x 0·005	2300–2800	(1)
Nickel, Molybdenum and Iron (cofelted)	¼ x 0·005	2300–2800	(1)
Molybdenum coated with Ni-Cr-Si brazing alloy (0·00001–0·001" thick)	¼ x 0·005	1800–2100 (brazing temp)	(1)
Molybdenum coated with Ni-Cr-B brazing alloy (0·00001–0·001" thick)	¼ x 0·005	1800–2100 (brazing temp)	(1)
Molybdenum and Tungsten fibers, both coated with Ni-Cr-Si brazing alloy (0·0001–0·001" thick)	¼ x 0·005	1800–2100 (brazing temp)	(1)
Molybdenum and Tungsten fibers both coated with Ni-Cr-B brazing alloy (0·0001–0·001" thick	¼ x 0·005	1800–2100 (brazing temp)	(1)

(1) Dry hydrogen atmosphere
(2) In air or dry hydrogen
(3) Neutral atmosphere, e.g. helium
(4) Either in air or a dissociated ammonia atmosphere
(5) Neutral or slightly oxidizing atmosphere

It is also possible in the practice of our invention to carry the metal fibers in a gaseous stream into the mold form or onto the sheet-forming web. In this instance the vibrational screening technique is eliminated and the fibers are directly blown or deposited, preferably after kinking, into the desired compact. Following such deposition the fibers are again bonded.

WHAT WE CLAIM IS :

1. A process for making a fibre metal compact, comprising releasing separate fibres in a gaseous medium so that the fibres are randomly oriented by the gaseous medium and collect into a randomly oriented mass of fibres, and bonding the fibres in the mass to each other at their points of contact, each fibre having a length of from 0·005 to 1·0", and a mean cross-section of from 0·0005 to 0·1" and not greater than one tenth of the length of such fibre.

2. A process as claimed in claim 1, which includes the step of separating the fibres before the fibres are released in the gaseous medium.

3. A process as claimed in claim 1, or 2 which includes the step of kinking the fibres.

4. A process as claimed in claim 1, 2 or 3 in which the fibres collect into the mass in a compactforming member and in which the mass is compressed to increase the density of the mass.

5. A process as claimed in claim 4, in which the steps of compressing and bonding the fibres are carried out simultaneously.

6. A process as claimed in any preceding claim, in which the gaseous medium is air and the step of releasing the fibres comprises allowing the fibres to fall under gravity through the air.

7. A process as claimed in any preceding claim in which the fibres are released in the gaseous medium by means of a vibrating screen.

8. A process as claimed in any of claims 1 to 5, in which the gaseous medium is a gaseous stream by which the fibres are carried after being released.

9. A process for making a fibre metal compact substantially as hereinbefore described with reference to the accompanying drawings.

10. A fibre metal compact formed by releasing separate fibres in a gaseous medium so that the fibres are randomly oriented by the gaseous medium and collect into a randomly oriented mass of fibres, and bonding the fibres in the mass to each other at their points of contact, each fibre having a length of from 0·005 to 1·0" and a mean cross-section of from 0·0005 to

0·1" and not greater than one tenth of the length of such fibre.

11. A fibre metal compact formed by the process claimed in any of preceding claims 2 to 9.

12. A fibre metal compact formed substantially as hereinbefore described with reference to the accompanying drawings.

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Printed for Her Majesty's Stationery Office by J. Looker Ltd., Poole, Dorset. 1962.
Published at The Patent Office, 25, Southampton Buildings, London, W.C.2, from which copies may be obtained

FIG. 1

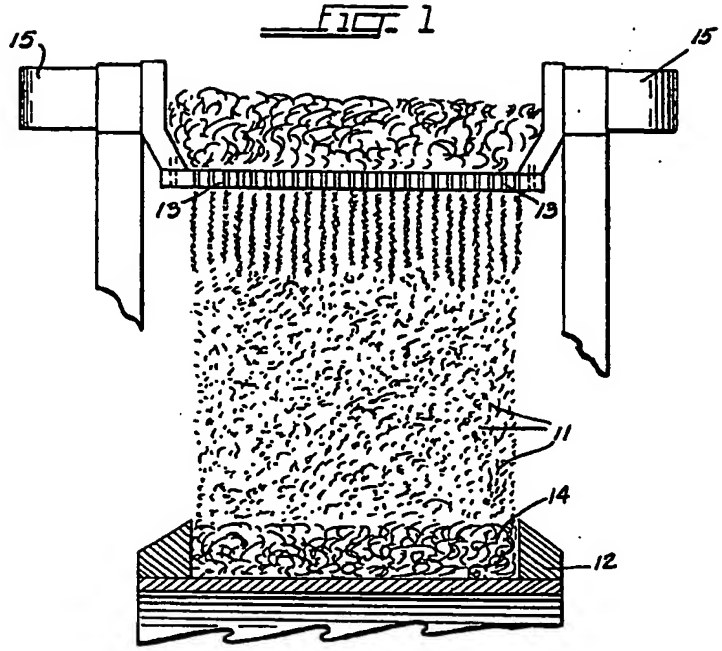


FIG. 3

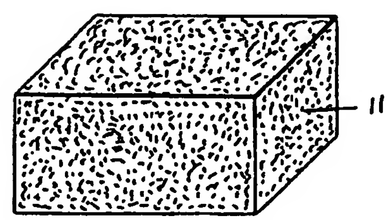
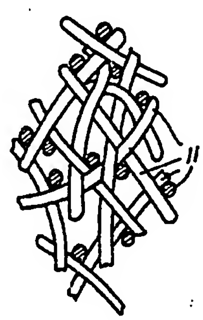


FIG. 4



889,583 COMPLETE SPECIFICATION
2 SHEETS
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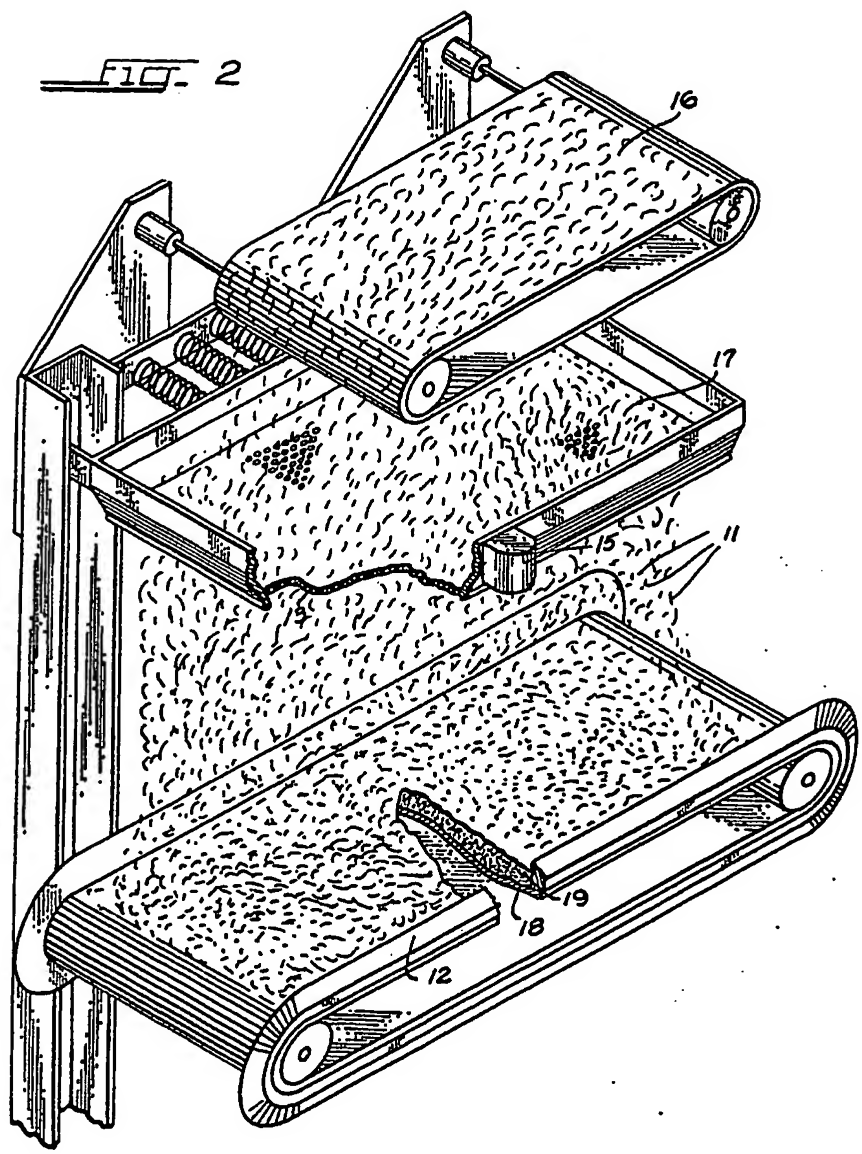
SHEETS 1 & 2

FIG. 2



889,583 2 SHEETS

COMPLETE SPECIFICATION

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SHEETS 1 & 2

FIG. 1

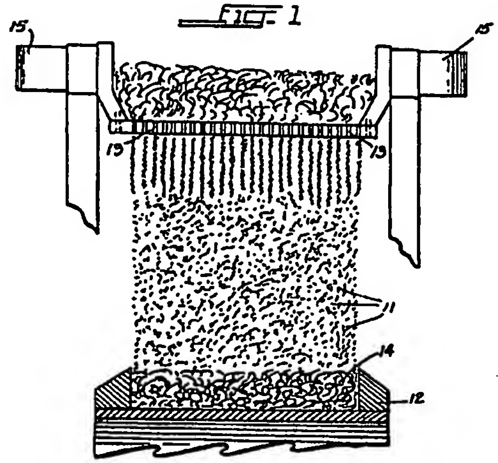

FIG. 2

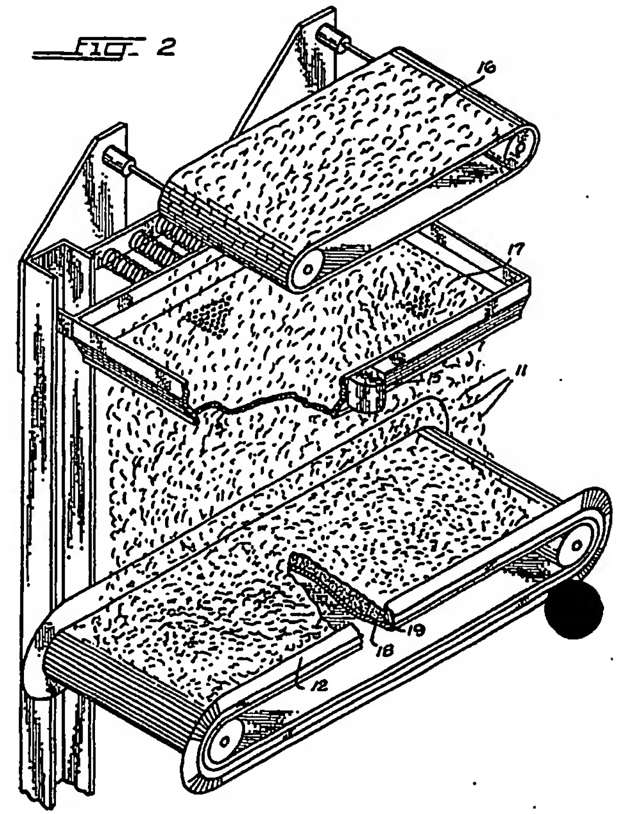

FIG. 3

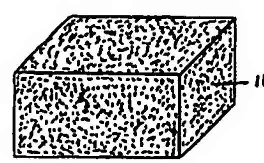

FIG. 4